



## ORIGINAL ARTICLE

# Mobile-bearing insert translational and rotational kinematics in a PCL-retaining total knee arthroplasty

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Accepted: 31 March 2009

## KEYWORDS

Mobile-bearing;  
 Posterior cruciate  
 ligament retaining;  
 Total knee  
 arthroplasty;  
 Kinematics

## Summary

**Introduction:** Total knee prostheses with a mobile-bearing insert were developed to provide nonconstrained joint range of motion while reducing friction forces. The purpose of this study was, based on weightbearing X-rays, to evaluate the mobility of the polyethylene tibial insert in relation to the femoral and tibial components. We studied the results of a cementless total knee arthroplasty (TKA) retaining the posterior cruciate ligament (PCL), with a mobile-bearing platform in rotation and anteroposterior translation (Innex<sup>®</sup> Anterior-Posterior Glide, Zimmer) with a mean 23-month follow-up duration after surgery.

**Hypothesis:** Both anterior-posterior tibiofemoral translation and intraprosthetic axial rotation occur between the mobile polyethylene insert and the tibial endplate.

**Material and method:** In a series of 51 primary TKA, the three-dimensional (3D) kinematics of the femoral, tibial, and mobile insert components were determined using a computerized matching system between the prosthetic 3D models and the radiographic images of the implants on three lateral follow-up weightbearing knee X-rays: films were taken in full extension, at 45° flexion, and at maximum flexion.

**Results:** There was a statistically significant increase in the internal rotation of the mobile tray with flexion, (up to a mean  $-3 \pm 3^\circ$  between the femoral box and the mobile tray [ $p < 0.0001$ ] and up to a mean  $-5 \pm 7^\circ$  between the tibial tray and the mobile tray [ $p < 0.0001$ ]). The mobile tray did not translate in relation to the tibial endplate from extension to 45° flexion

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( $0 \pm 2$  mm [range:  $-5$  to  $6$  mm]). However, from  $45^\circ$  to maximum flexion, a statistically significant mean  $1 \pm 2$  mm (range:  $-2$  to  $9$  mm) of anterior translation ( $p < 0.0001$ ) was found.

**Discussion.** — The extent of insert mobility varies from one study to another. Some have reported relatively limited mobility stemming from a superior surface that is not highly congruent, (thus allowing anterior-posterior and mediolateral translation through gliding of the femur in contact with the insert). Other studies have reported mobile-bearing tray mobility in relation to the tibial endplate and minimal rotation at the femoral component level. In this series of PCL retaining TKA with a mobile-bearing platform, the mobile-bearing platform showed a progressive increase in internal rotation during flexion. Most of this rotational mobility occurred between the mobile platform and the tibial endplate, confirming our hypothesis. However, with flexion, the femoral component increased its mobility relatively to the platform. During flexion, an anterior-posterior translation occurred between the femoral implant and the tibial insert, and between the tibial insert and the tibial endplate, but the direction of the mobile tibial insert translation remained unpredictable with this unconstrained implant design used.

Level of evidence: Level IV. Prospective non-controlled therapeutic study.

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## Introduction

Total knee implants with a mobile-bearing tray were developed to provide nonconstrained joint range of movement with low friction force. The joint's freedom of movement in rotation and the potential anterior-posterior displacement of the tibial insert guarantee the anatomic alignment of the implants, i.e., the mobile-bearing tray is able to position itself based on the forces applied by each individual and the local anatomic conditions [1,2].

Several mobile-bearing tray designs have been devised with the aim of optimizing the congruence between the tibial and femoral components for any flexion. Reducing the level of constraints at the component–mobile-bearing tray interface, mobile tray knee implants should also reduce the potential risk of polyethylene wear and aseptic loosening [3].

The aim of this study was to evaluate the mobility of the polyethylene tibial insert in relation to the femoral and tibial components within a cementless posterior cruciate ligament (PCL)-retaining total knee arthroplasty (TKA) with a mobile-bearing tray in rotation and anterior-posterior translation (Innex® Anterior-Posterior Glide, Zimmer, Warsaw, USA). Based on weightbearing X-rays. Given the implant's characteristics and following Dennis et al.'s report [4], we hypothesized that femorotibial anterior-posterior translation and intraprosthesis axial rotation should occur between the mobile-bearing polyethylene insert and the tibial endplate. Finally, as reported by Fantozzi et al. [2], we expected increased mobility of the femoral component in relation to the mobile-bearing polyethylene insert as flexion increased, caused by the progressive decrease in congruence.

## Material and method

The kinematic analyses were performed on a series of 51 patients having undergone primary TKA. No revision cases were included in the study. The mean age at surgery was  $71 \pm 8.1$  years (range: 22 to 84 years). All the knee prostheses were implanted via an anteromedial approach. Any tibial insertion lesions of the PCL during tibial cutting were mini-

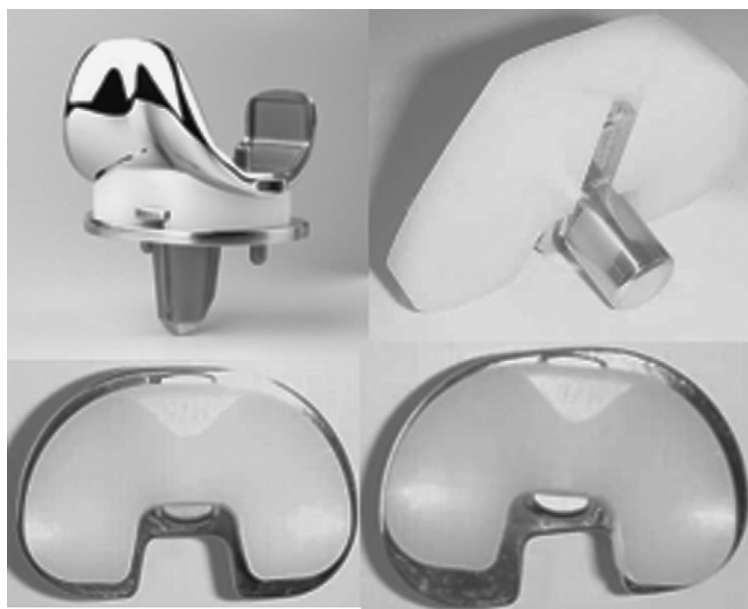
mized by preserving a posterior tibial bone block in front of the PCL's tibial insertion.

All patients had a cementless PCL-retaining TKA with a mobile tray in rotation and posterior-anterior translation (Innex® Anterior-Posterior Glide, Zimmer, Warsaw, USA). This prosthesis ensures high congruence between the femoral component with a variable radius of curvature and the tibial insert at full extension and provides free mobility of the polyethylene tibial insert in rotation and anterior-posterior translation in relation with the tibial endplate (Fig. 1).

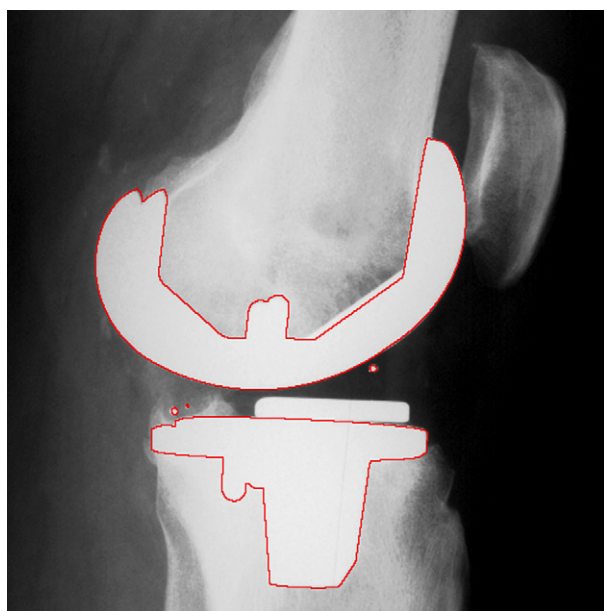
The bone cuts were made as described by Lerat et al. [5]. The extramedullary ancillary for the tibial cut was set to provide  $6^\circ$  of posterior tibial slope. Final ligament release was performed once the trial implants were in place.

At a mean follow-up of 23 months after surgery (range: 10 to 65 months), all patients had three follow-up lateral weightbearing radiographs: views in full extension, with  $45^\circ$  flexion and with maximum flexion. The clinical result of the TKA was judged favorable in all the patients (Hospital for Special Surgery [HSS] knee score greater than 90 points) with no ligament laxity or pain.

Three metallic bearings were inserted in a known position in each polyethylene tibial insert at manufacture. Three-dimensional (3D) computerized models of these bearings within the inserts were generated by computer. A radiographic technique was used to measure the 3D position of the femoral component, the tibial endplate and the mobile-bearing insert in relation to each other during flexion (Fig. 2). The focal distance on the X-rays was known. The 3D position and orientation of the implant components were determined using a computer image-matching system comparing the 3D implant models and the X-ray image of the implants (Kneetrack® software) [6]. This required the X-rays to be numbered beforehand. Strictly lateral radiographs were not necessary using this software given that the implants would later be modeled in 3D. The X-ray projection parameters (principal distance, principal point) were known. The surface of the 3D implant models was projected onto the digitized radiographs, and the final 3D position was determined by superimposing the 3D models' contours onto the X-ray images of the implants. The results of this procedure showed a mean error of  $0.58$  to  $1.08^\circ$  for the rotation measurements and  $0.5$  to  $1.0$  mm for translation in the sagit-



**Figure 1** Innex CR® prosthesis (Zimmer): the design of this total knee prosthesis provides unlimited mobility of the polyethylene tibial insert in rotation and in anteroposterior translation along its guide rail.



**Figure 2** Matching procedure for the femoral and component models and the mobile-bearing tray bearings using Kneetrack® software.

tal plane [7]. Joint kinematics were determined based on the 3D position of each prosthesis component according to the measurement conventions for the knee [8].

The Student *t* test was used to compare the means of the parameters studied (Stat View 5.0®, SAS Institute Inc.).

## Results

### Joint range of movement

The mean knee flexion angle found 23 months postoperatively was  $104 \pm 12^\circ$  (range: 72 to  $127^\circ$ ). The entire range of

flexion occurred between the femoral component and the mobile-bearing tray. No flexion was observed between the mobile-bearing tray and the tibial endplate.

The mean intraprosthesis hyperextension (the software displayed a negative sign) was  $-6 \pm 9^\circ$  (range:  $-25$  to  $21^\circ$ ). No hyperextension was found between the mobile-bearing tray and the tibial endplate.

The mean weightbearing joint range of movement was  $110 \pm 14^\circ$  (range: 64 to  $136^\circ$ ).

### Rotation

On the successive films, a progressive internal rotation of the tibial endplate was observed with flexion in relation to the femoral box, from a mean  $-1 \pm 7^\circ$  (range:  $-19$  to  $13^\circ$ ) in full extension to a mean  $-9 \pm 7^\circ$  (range:  $-24$  to  $3^\circ$ ) in maximum flexion (Table 1). There was a statistically significant increase in the internal rotation of the mobile-bearing tray with flexion up to a mean  $-3 \pm 3^\circ$  between the femoral box and the mobile-bearing tray ( $p < 0.0001$ ) and up to a mean  $-5 \pm 7^\circ$  between the tibial tray and the mobile-bearing tray ( $p < 0.0001$ ).

Sixteen patients were assessed at two follow-up times (3 months and 21 months after implantation). We found no modifications in rotation between the femoral component and the mobile-bearing tray at these two follow-up times.

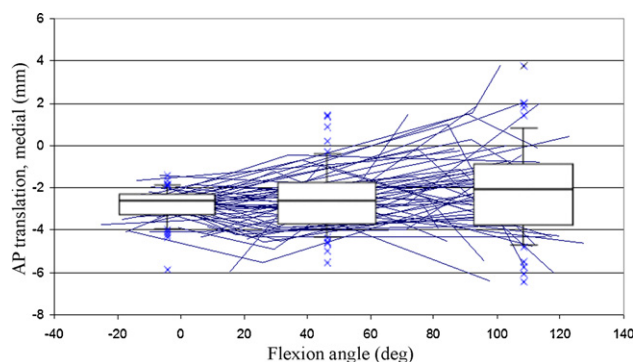
### Anterior-posterior translation

In relation to the mobile-bearing tray, the medial femoral condyle showed no translation, on average, from full extension to flexion at  $45^\circ$  and from  $45^\circ$  flexion to maximum flexion ( $0 \pm 2$  mm [range:  $-2$  to 5 mm];  $0 \pm 3$  mm [range:  $-7$  to 7 mm], respectively) (Fig. 3).

The lateral femoral condyle showed a statistically significant mean posterior translation ( $p < 0.0001$ ) of  $1 \pm 1$  mm

**Table 1** Mean axial rotation between the three prosthetic components.

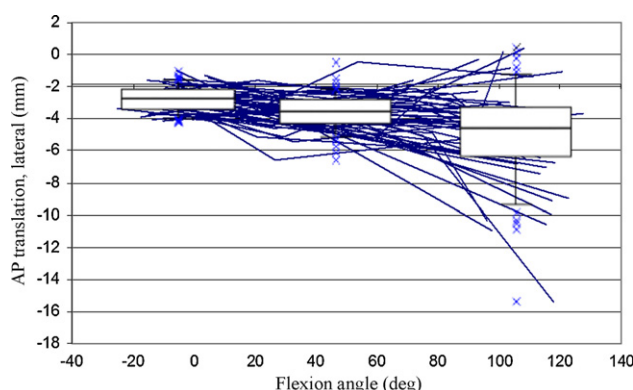
23 months after surgery	Full extension(°)	45–90° flexion(°)	Maximum flexion(°)
Tibiofemoral kinematics	$-1 \pm 7$	$-5 \pm 8$	$-9 \pm 7$
Femur in relation to insert	$0 \pm 1$	$-1 \pm 2$	$-3 \pm 3$
Insert in relation to tibia	$-1 \pm 6$	$-4 \pm 7$	$-5 \pm 7$



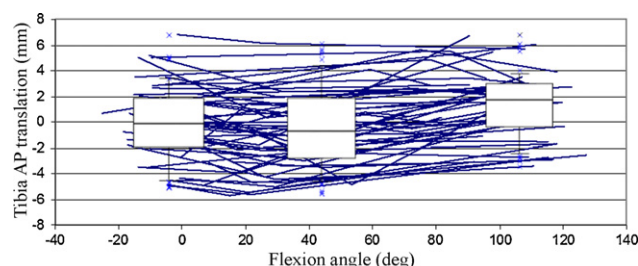
**Figure 3** Anterior-posterior translation of the medial femoral condyle in relation to the mobile polyethylene insert according to flexion: there was no modification in the position in anterior-posterior translation of the medial condyle compared to the polyethylene mobile-bearing insert for each position (box plots). The mobility profile of the polyethylene insert (individual lines) was not constant from one patient to another. AP trans med: Anterior-posterior translation, medial side.

(range:  $-4$  to  $3$  mm) from extension to  $45^\circ$  of flexion, and  $1 \pm 3$  mm (range:  $-10$  to  $5$  mm) from  $45^\circ$  of flexion to maximum flexion ( $p=0.004$ ) (Fig. 4).

On average, the mobile-bearing tray did not translate in relation to the tibial endplate from extension to  $45^\circ$  flexion ( $0 \pm 2$  mm [range:  $-5$  to  $6$  mm]). However, from  $45^\circ$  flexion to maximum flexion, a statistically significant mean  $1 \pm 2$  mm



**Figure 4** Anterior-posterior translation of the lateral femoral condyle in relation to the polyethylene mobile-bearing insert versus flexion: the posterior translation of the lateral femoral condyle compared to the mobile-bearing insert was a mean  $2$  mm from  $0^\circ$  to  $105^\circ$  flexion (box plots). The mobility profile of the polyethylene insert (individual lines) was not constant from one patient to another. AP trans lat: Anterior Posterior Translation Lateral Side.



**Figure 5** Anterior-posterior translation of the polyethylene mobile-bearing insert in relation to the tibial endplate versus flexion: on average, the mobile-bearing insert did not significantly move in relation to the tibial tray from  $0^\circ$  to  $45^\circ$  of flexion, but showed an anterior displacement from  $45^\circ$  flexion to maximum flexion (box plots). The mobility profile of the insert from extension to maximum flexion (individual lines) was not constant from one patient to another. APtrans: Anterior Posterior Translation.

(range:  $-2$  to  $9$  mm) anterior translation ( $p<0.0001$ ) was found (Fig. 5).

## Discussion

The implants as well as the surgical technique have a substantial impact on the weightbearing kinematics of TKA implants [9] and on their survival curve [10]. Ligament and soft tissue balance can also have a significant effect on joint kinematics, particularly with nonconstrained total knee implants [9]. Mobile-bearing TKA kinematics can also be limited by periprosthetic fibrosis resulting from the mobile-bearing insert [11].

The main limitation of this study lies in the fact that the X-rays were taken with the patients in a static position. Nevertheless, the weightbearing X-ray results could be compared directly to the vast majority of the series reported in the literature, whether they were clinical (deep flexion, flexion when kneeling, prolonged upright position) or radiographic (CT, MRI) [2,4,9–12]. Our study did not investigate a consecutive series of patients. However, the operative technique and the implants did not change. No clinical selection was made and patients were included based on radiographic criteria, i.e., whether the three metallic bearings of the mobile-bearing tray could be identified, which was necessary to assess the implant's 3D kinematics. Consequently, this should not significantly influence the validity of the results that we believe are representative of the weight-bearing knee's kinematics obtained for the type of total knee prosthesis used.

The range of insert mobility varies from one study to another. Fantozzi et al. [2] and Garling et al. [11] reported



relatively limited mobility because the superior surface was insufficiently congruent, resulting in anterior-posterior and mediolateral translation through the femur gliding on the insert contact. In these studies, in extension, the femoral component showed more axial rotation on the polyethylene insert than did the insert itself in relation to the tibia, such that the femur slid on the mobile-bearing tray [11]. Three theoretical explanations can be given: insufficient congruence between the femoral component and the insert, formation of fibrous tissue between the mobile-bearing tray and the tibial endplate, and presence of fibrous tissue surrounding the insert, which may restrict its freedom of movement. Dennis et al. [4] and Komistek et al. [12] reported mobile-bearing tray mobility in relation to the tibial endplate and a minimal rotation of the femoral component. In our study, the mobile-bearing tray was mobile in all positions of knee flexion. This range of movement for the most part occurred between the insert and the tibial tray. However, with flexion, an increase in femur range of movement when in contact with the insert was found, probably caused by the reduction in the congruence of the implant components.

Rotation of the polyethylene insert in mobile-bearing TKA seems highly variable depending on the series and the implant design. In Garling et al.'s study [11] on PCL-retaining implants, internal rotation of the mobile-bearing tray was 5.9° and that of the femoral component on the insert was 10.8°. Greater internal rotations of the mobile-bearing tray with flexion, on the order of 8.4 to 10.3°, have also been reported by Dennis et al. [4]. In our study, the mobile-bearing tray showed a progressive increase in internal rotation with flexion. The rotation was confined to the rotation between the insert and the tibial endplate when the knee was in extension. With the increase in flexion, the rotation of the femoral component on the mobile-bearing tray increased.

Dennis et al. [4] reported a limited modification in mobility in rotation of the mobile-bearing tray at follow-up, with a maximum of 8.5° at 3 months and 9.8° at 15 months after surgery. However, we found no modification in rotation between the femoral component and the mobile-bearing tray over time. We found a nonstatistically significant increase of 1° rotation between the mobile-bearing tray and the tibial endplate at 30° of flexion and in maximum flexion ( $p=0.8353$ ;  $p=0.8656$ , respectively), with a maximum of 7° of internal rotation at 23 months in maximum flexion. These observations do not support the notion that mobile-bearing tray rotation increases with time, but this should be confirmed on a larger group of patients.

With the LCS AP Glide implant, Dennis et al. [4] found a mean 5.6 mm (range: 1 to 12.5 mm) mobile-bearing tray anteroposterior translation. Paradoxical anterior translation, rather than a posterior translation of the mobile-bearing tray with flexion, was observed in a few patients. Paradoxical anterior translation of the femoral component during flexion is known to sometimes be harmful for flexion. It can result in increases in patellar constraints, hamstring twitching, and theoretically an earlier femorotibial posterior bone contact with encroachment of the soft tissues [3]. Mobile-bearing and posterior-stabilized tray prostheses seem able to reproduce posterior condylar

translation. Argenson et al. [13] report posterior translation amounting to 3.9 mm for the medial condyle and 8.1 mm for the lateral condyle in maximum flexion. In the present study, during flexion, we found a significant variation in the translation of the mobile-bearing tray, which was also distributed between anterior and posterior translation, with a mean translation value of 0 mm. Nevertheless, this value does not reflect the anteroposterior translation of the healthy knee without a prosthesis [14].

In this series of PCL-retaining mobile-bearing tray TKA, the mobile-bearing trays showed a progressive increase in internal rotation with flexion. In agreement with our initial hypothesis, we were able to conclude that most of the mobility occurred between the mobile-bearing tray and the tibial endplate. However, with flexion, the femoral component increased its mobility on the tray. During flexion, anteroposterior translation occurred between the femoral box and the tibial insert, and between the tibial insert and the tibial baseplate, but the direction of the mobile-bearing insert's translation seemed to be unpredictable with the nonconstrained prosthesis design used.

## Conflicts of interests

None.

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